Television Receiver Optimization in the Presence of Adjacent Channel Interference

O. Bendov and C.B. Patel

Abstract -- **Improved DTTV reception in a crowded spectrum can be attained by automatically shifting the front-end filter and by automatically steering the pattern of the receive antenna. This paper shows how 3rd order intermodulation distortion (IM_3) and other interference due to strong adjacent channels can be minimized and the signal to noise ratio maximized for optimally robust reception.**

Index Terms -- **DTTV, adjacent channels, interference, optimization, AGC, front-end filter, steerable antenna array.**

I. INTRODUCTION

Before digital terrestrial television (DTTV) broadcasting the service area for a transmitter assigned a channel N did not receive power from a transmitter assigned to the first lower adjacent (N-1) channel or from a transmitter assigned to the first upper adjacent (N+1) channel. These first adjacent (N±1) channels were part of the so-called "taboo" channels that were not locally assigned.

Prior to the introduction of DTTV, the absence of first adjacent channels permitted a tunable front-end filter with passband well above and below the passband of the N±1 channels without incurring penalty in the robustness or the quality of reception. This relatively wide passband provided for rapid capture and performance of the desired channel. The absence of strong adjacent-channels generally precluded undesirable intermodulation (IM) and cross-modulation (XM) products from being generated in a TV receiver.

With the introduction of DTTV, the Federal Communications Commission (FCC) granted each analog TV broadcaster an additional channel assignment for transmitting DTTV. In each market, this doubled the number of channels assigned. At the same time the FCC reduced the spectrum available for television channels by eliminating former TV channels 52 through 69. The FCC accommodated these changes by assigning previously "taboo" channels for DTTV.

There are more than 200 markets in the U.S. where high-power first adjacent channels are expected to operate at least through the transition period from analog to digital television. New technologies, such as on-channel repeaters, synchronized or not, are sure to exacerbate the interference to robust reception. Certainly, television reception in a packed spectrum promises to be a new experience for consumers, consumer electronics manufacturers and broadcasters.

In markets where TV transmissions exist on one or both first adjacent channels, DTTV reception will be degraded by the generation of third-order IM products (IM_3) generated at the transmitter and at the receiver's mixer and amplifiers[1]. Since the IM_3 spectrum of DTTV channels extends into one channel above and one channel below the channel in which it is generated, the IM_3 power generated by the undesired (N+1) or (N-1) adjacent channel manifests itself as co-channel noise in the desired (N) channel. The adjacent-channel interference to television reception will become more pronounced as more stations raise power to the maximum level allowed and more receivers penetrate the consumer market.

II. STATE OF THE AGC ART

Automatic gain control (AGC) information is normally derived from the desired channel after the signal is down-converted and bandpass filtered to 6 MHz. The derived AGC[2] is then applied to the intermediate-frequency (IF) amplifier and the delayed AGC to the radio frequency (RF) circuit as needed by the wide dynamic range of DTTV reception. In that way the system's noise figure is maintained as low as possible and the gain as high as possible without overloading the IF amplifier. Thus, the level of the desired channel alone controls the AGC.

If an undesired adjacent channel signal is present, its signal level at the receiver's front end could, in many locations, be much stronger than the signal level of the desired-channel. Therefore, in the case a weak desired channel, the AGC to increase the gain for both the desired channel, which is weak, and also for the undesired adjacent channel, which is strong. With increased gain, the strong undesired signal could over-drive the RF amplifier and/or a mixer, causing the generation of unacceptably large IM_3 and XM products that fall into the weak desired channel. The spectral width of these products is three channels wide, raising the noise power in the desired channel. Clearly, the

O. Bendov is president of TV Transmission Antenna Group Cherry Hill, NJ USA.
(e-mail: odedbendov@comcast.net)
C.B. Patel is consultant to Samsung, Hopewell, NJ USA.
(e-mail: cbnhdtv@comcast.net)

automatic application of AGC in the presence of stronger adjacent channels could lead to reception failure.

Simply narrowing the front end filter to restricting its passband to little more than a channels width to better suppress the strong adjacent channel signal could theoretically provide a partial solution to this problem. In practice, it is extremely difficult to implement a single channel filter with linear phase through the selected channel in a consumer-grade commercial DTTV receiver.

An improved two-stage AGC, one based on wideband response controlling the mixer and another based on narrowband response controlling the IF stages would provide some improvement in reducing the potential overload of the mixer by strong undesired channels at the expense of reducing the gain of the desired channel.

III. IMPROVED RECEIVER DESIGN*

Within the receiver, the IM_3 and XM levels could be reduced in three ways. First, the passband of the front end filter could be detuned to minimize the transfer of the undesired channel power to the tuner. Second, a "smart" antenna, if available, could have its radiation pattern steered so as to direct a low gain sector, possibly a null, in the direction of the undesired channel. Third, because it is well known that for 1 dB of inserted attenuation the undesired IM_3 and XM generated at the front end are attenuated by 3 dB, additional attenuation could be inserted ahead of the receiver's front-end. The inserted attenuation improves signal-noise ratio (SNR) at the expense of the desired signal level. Any or all of the three approaches to the reduction of IM_3 and XM may be applied in order to improve reception.

The ability to improve DTTV reception in difficult environments using an antenna array with steerable pattern has already been demonstrated[3,4]. The present paper demonstrates that by combining a controlled tunable front end filter, a variable attenuator and an antenna with steerable pattern, improved reception over that available from a steerable antenna pattern alone can be attained. The improved reception results from improving the SNR of the desired channel by reducing the adjacent channel's power and its spectral regrowth into the desired channel, which is generated at the adjacent channel's transmitter and at the front-end of the TV set.

Central to the new design is a front end filter that can be automatically shifted so as to minimize the amount of energy from the undesired adjacent channel(s) that reaches the mixer. Figure 1 shows how this filter would be shifted based on the energy in the undesired channels. The front end filter can be shifted by selective detuning or by switching in an additional high pass or low pass filter (or both) after the bandpass filter.

Figure 2 is a schematic diagram of the proposed design, which includes a new detunable front-end filter, controlled attenuator and an antenna array with variable pattern, all electronically-controlled. Although the filter, attenuator and array can each be used independently to improve reception robustness in the presence of strong adjacent channels, it is the combination of the three that makes for an optimum robustness. The desired settings for the array pattern processor, attenuator and filter detuning are stored in a PROM, after initial SETUP, for each channel. Also stored in the PROM are instructions on how far to detune the front-end filter in the event that interference from strong adjacent channels is detected. The amount of shift, programmed at the factory, depends on the designed bandpass. For example, if the bandpass were three channels wide, the nominal shift would be one channel.

The importance of antenna pattern, filter detuning and inserted attenuation toward minimizing the system's IM_3 noise generated in the receiver by each undesired adjacent channel in the desired channel could be gleaned from equation (1):

$$IM_3(dBm) = 3\begin{bmatrix} 10Log(KP_R) + G_{\theta,\phi}(dB) \\ - L(dB) - S(dB) \end{bmatrix} - 2IP_3(dBm) \qquad (1)$$

where:

KP_R = Incident adjacent power factor.

$G_{\theta,\phi}$ = Antenna pattern gain reduction factor in the direction of the undesired adjacent channel.

IP_3 = 3rd order intercept point of the mixer/IF block.

S = Filter selectivity of the undesired adjacent channel.

L = Insertion loss.

From (1), a 1 dB reduction in the antenna gain toward the undesired channel or an increase of 1 dB in the insertion loss between the antenna and the mixer, or in the selectivity of the front end filter, would cause the IM_3 to be lowered by 3 dB. For example, if the gain reduction factor in the direction of the undesired adjacent channel is zero but filter detuning increased the selectivity by 3 dB and added attenuation increased by 1 dB, then IM_3 noise generated at the receiver would be lowered by 12 dB. At the same time the desired signal level was decreased only by 1 dB, thus providing significant improvement in SNR.

When the receiver is first installed, it undergoes SETUP by a press of a button on the remote control (or

* Patent pending

on the TV set). During SETUP, all discrete patterns of the array are scanned for each channel. Usually the number of pattern options is between 3 and 13, allowing one for a bypass set-top or rooftop antenna. At the end of SETUP, the optimum array pattern, filter detuning and attenuator information are stored for each channel and the set is ready for program viewing. The stored SETUP information remains in memory and is not changed until SETUP is initiated again.

The SETUP process can be initiated at the user's discretion at any time for one or all channels. For example, entering SETUP32 will initiate the process for channel 32 whereas entering SETUP will initiate the process for all channels. There would be several reasons for repeating the setup procedure after initial installation. Additional SETUP or SETUPmn would be desirable as new channels become available, or if the antenna has been replaced or moved to another location or if degradation to reception robustness is perceived. During SETUP, four metrics are evaluated at each antenna pattern:

1. SNR above threshold or point of failure (POF).
2. $ACPR_+$ = average power in the desired channel relative to the power in the first upper adjacent channel.
3. $ACPR_-$ = average power in the desired channel relative to the power in the first lower adjacent channel.
4. Inserted attenuation between the antenna and the receiver's bandpass filter.

SNR data† above POF is extracted after successful demodulation. If the noise in the desired channel is too high or if the desired signal is too low, SNR data may not be immediately available. The other metrics, the relative average power in the adjacent channels and the inserted attenuation are always available. Wideband RF AGC is applied throughout the SETUP process. The IF AGC as well as the AGC to the demodulator circuits is unaffected by the optimization routine.

III. OPTIMIZATION

For each of total M channels and total of K available antenna patterns, start with channel m=1 and pattern k=1. Start with filter optimization for pattern k=1 and channel m=1. The inserted attenuation and SNR are set to zero and the bandpass filter is set to its normal, symmetric mode.

If both $ACPR_+$ and $ACPR_-$ are above a preset maximum level (indicating no adjacent channel noise) and no SNR data is available, the channel is temporarily unavailable for pattern k and, provided k<K, the next pattern is switched into. If both $ACPR_+$ and $ACPR_-$ are above a preset maximum and SNR data is available, the channel is flagged AVAILABLE for pattern k and the SNR, filter position and attenuation are stored and, provided k<K, the next pattern is switched into.

If either $ACPR_+$ or $ACPR_-$ is above a minimum preset level, the passband filter is detuned up or down, depending on modulation and filter design, to minimize the power in the adjacent channels that reaches the mixer.

After detuning the inserted attenuation is increased for as long as the SNR improves, or if SNR data is not available and either ACPR- or $ACPR_+$ are below a preset level, for as long as the lower of the two ACPRs is increasing. If SNR above POF is not available at the end of attenuation insertion, the channel is declared temporarily unavailable. If SNR above POF is available at the end of attenuation insertion, the channel is declared AVAILABLE.

If the filter and the attenuator optimization for the current pattern result in improved SNR, the new SNR, filter shift and attenuation values replace the previously stored values. Continue until k=K and then repeat for the next channel until m=M. Figure 3 shows the optimization's flow chart for fixed reception.

At the end of the setup process the antenna pattern, filter detuning and insertion loss that yielded the maximum SNR for each channel are stored for immediate front end optimization when that channel is selected for viewing. A channel, for which acceptable SNR data could be acquired for any k, is stored as AVAILABLE for viewing. The stored data remains in memory until SETUP is reactivated. Channels for which SNR data could not be acquired are skipped and are nor available for viewing.

During program viewing the wideband RF AGC may be automatically switched to narrowband RF AGC if the power in the adjacent channels is low or non-existent.

IV. MOBILE RECEPTION

Mobile reception usually requires a diversity antenna. However, the rapid changes in signal power, multipath and depolarization make the SETUP algorithm impractical for mobile application. For these reasons,

† Standard chips, for example OREN's OR51210 Digital VSB Demodulator provide SNR data for 8-VSB receivers and Mitsubishi's MB87J217A provide SNR data for COFDM receivers.

only filter detuning in response to strong adjacent channel is recommended.

For mobile reception, a diversity antenna, such as shown in Fig. 4 could be employed. The antenna is made of two tilted dipoles separated by at least ¼ wavelength and pasted on the car rear or front window. The two dipoles are connected to a hybrid whose outputs are the sum [+ +] and difference [+ –] of the individual pattern of each dipole. A two-pole, single-throw high-speed switch selects either the sum or the difference pattern. While switching, from [++] to [+ –] the shunt switch S+ – is temporarily closed to avoid loss of carrier. Similarly, while switching, from [+ –] to [+ +] the shunt switch S+ + is temporarily closed to avoid loss of carrier. The antenna provides space and polarization diversity. Pattern selection is based on the maximum SNR if available or maximum signal level if SNR is unavailable. The front-end filter may be continuously detuned. The decision on whether or not to detune the filter depends on the ACPRs. Each metric is integrated with a time constant long enough to smooth the variations in the received power. The wideband AGC is always on.

When a channel is tuned into, the last antenna, attenuator and filter configuration, previously stored, are initiated. If $ACPR_+ > ACPR_-$ and is above a minimum preset level, the passband filter is detuned to increase the selectivity loss in the N-1 channel. If $ACPR_- > ACPR_+$ and is also above the same minimum preset level, the passband filter is detuned to increase the selectivity loss in the N+1 channel. If $ACPR_+ = ACPR_-$ within a preset tolerance, or if no power is detected in the adjacent channels, the filter's remains unchanged. The second antenna pattern is tried. Additional trials are also made when the SNR or the signal level fades below a preset level. If the improvement is above a preset level, the last switched pattern continues to be in use. Figure 5 shows the optimization's flow chart for mobile reception.

V. SUMMARY

The transition to digital television will expose many communities in the U.S. and elsewhere to new interference from adjacent channels. In the US alone there are more than 200 communities where at least one adjacent DTTV channel must be accommodated due to lack of spectrum.

At present there are no minimum performance standards mandated by the regulatory agencies for digital television receivers. Transmitter standards, set by the FCC and now in effect, have already shown to be inadequate[5] even if the desired and adjacent channels are collocated. The interference by adjacent channels could only be exacerbated with the introduction of additional transmitters, especially those not collocated, such as on-channel repeaters whether synchronized or not and with receivers not designed to minimize the interference expected from adjacent channels.

Some relief from the expected interference could be gained by tightening the transmission standard specifying the maximum allowable sideband splatter of the undesired adjacent channels into the desired channel. However, a major benefit could be gained by designing a "smart" receiver, which automatically optimizes the receiver's front-end to present conditions. This paper shows how a "smart" front-end would be implemented in practice.

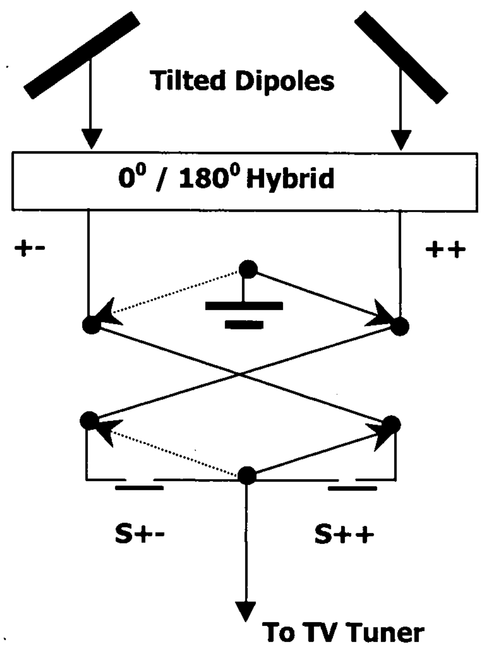

Figure 4: A Mobile Antenna with Diversity

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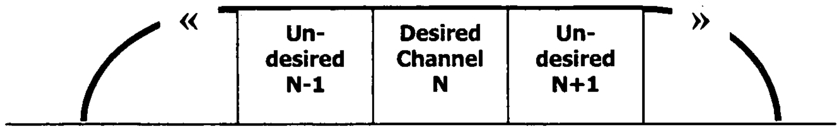
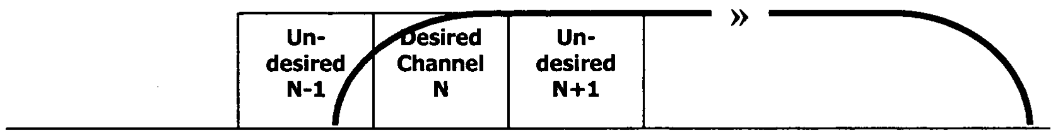
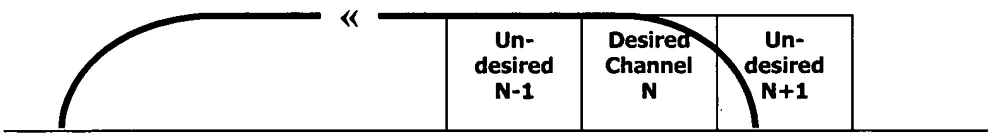
[2] Sun-Hoon Moon et.al., "Spatial Diversity Technique for Improvement of DTV Reception Performance," IEEE Transactions on Consumer Electronics, Vol. 49, No. 4, November 2003.
[3] O. Bendov, "Smart, Active and Concealable Antenna Array for Portable Television Reception," IEEE Transactions on Broadcasting, March 2004.
[4] Koichi Oya, "Method and Apparatus for Changing Automatic Gain Control Points of digital television Signals," US Patent # 6,421,098 B1, July 16,2002
[5] O. Bendov et. al., Planning Factors for Fixed and Portable DTTV Reception," to be published in the IEEE Transactions on Broadcasting,.



Filter Normal Position: Level of N-1 Channel = Level of N+1 Channel
High level undesired reduced by front-end switched attenuator



Filter Position #1: Level of N-1 Channel > Level of N+1 Channel
Shifted filter reduces level of N-1 channel at the front-end



Filter Position #2: Level of N-1 Channel < Level of N+1 Channel
Shifted filter reduces level of N+1 channel at the front-end

Figure 1: Front-end Filter Shifting to Minimize Interference into the Desired Channel

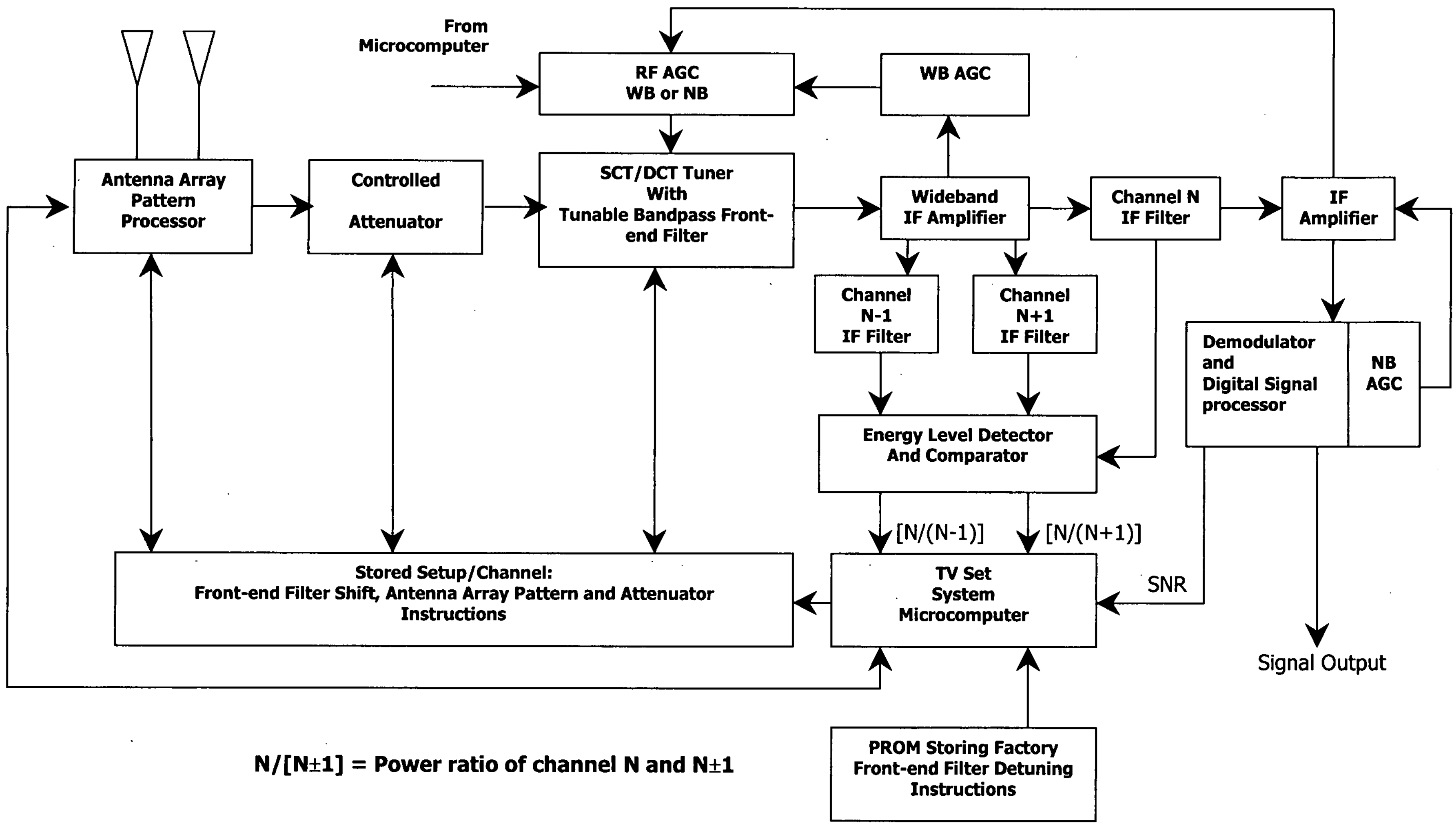


Figure 2: Schematic Diagram of the Processing and Control Circuits

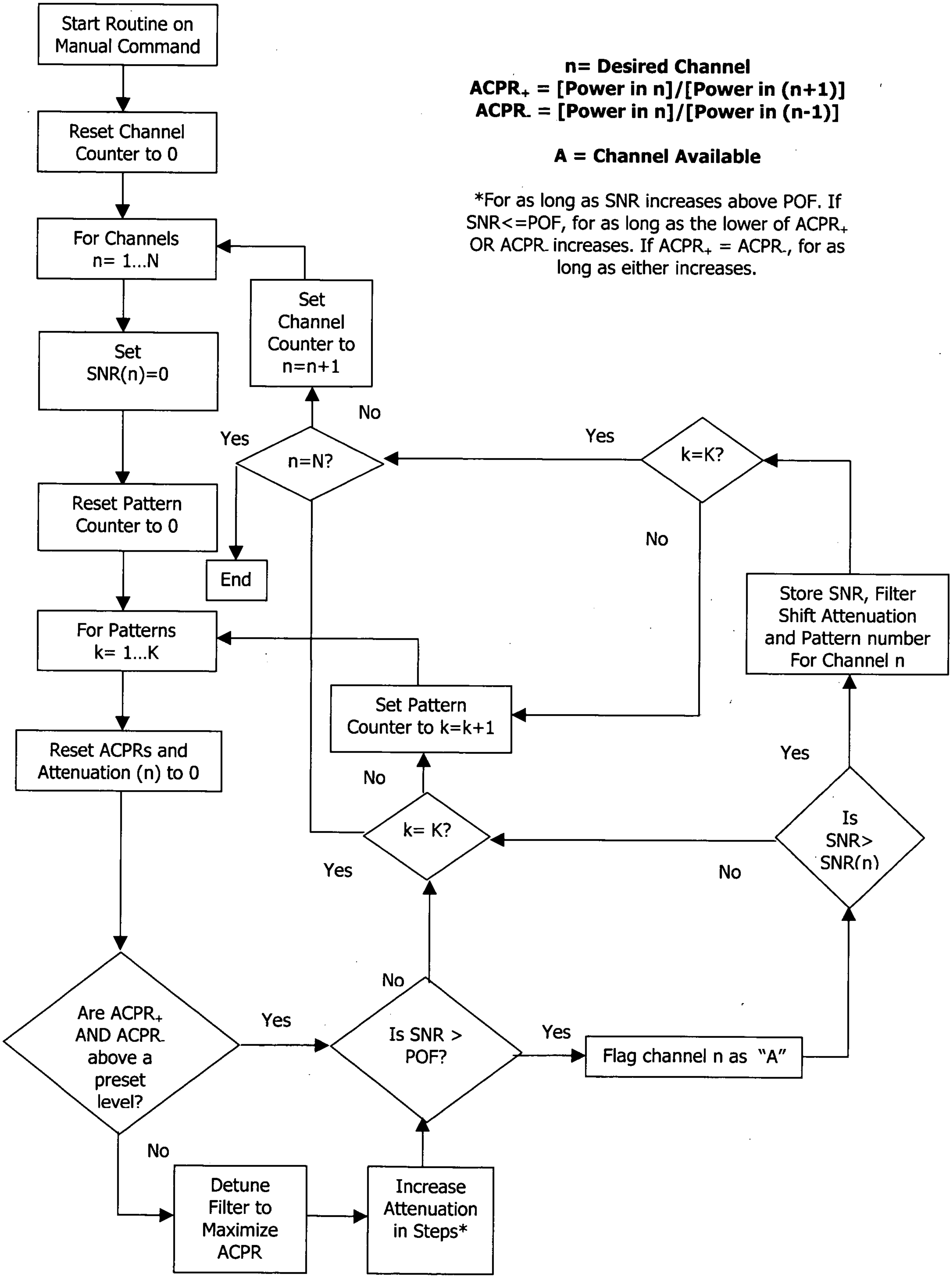


Figure 3: Initial Optimization Algorithm for Fixed Reception

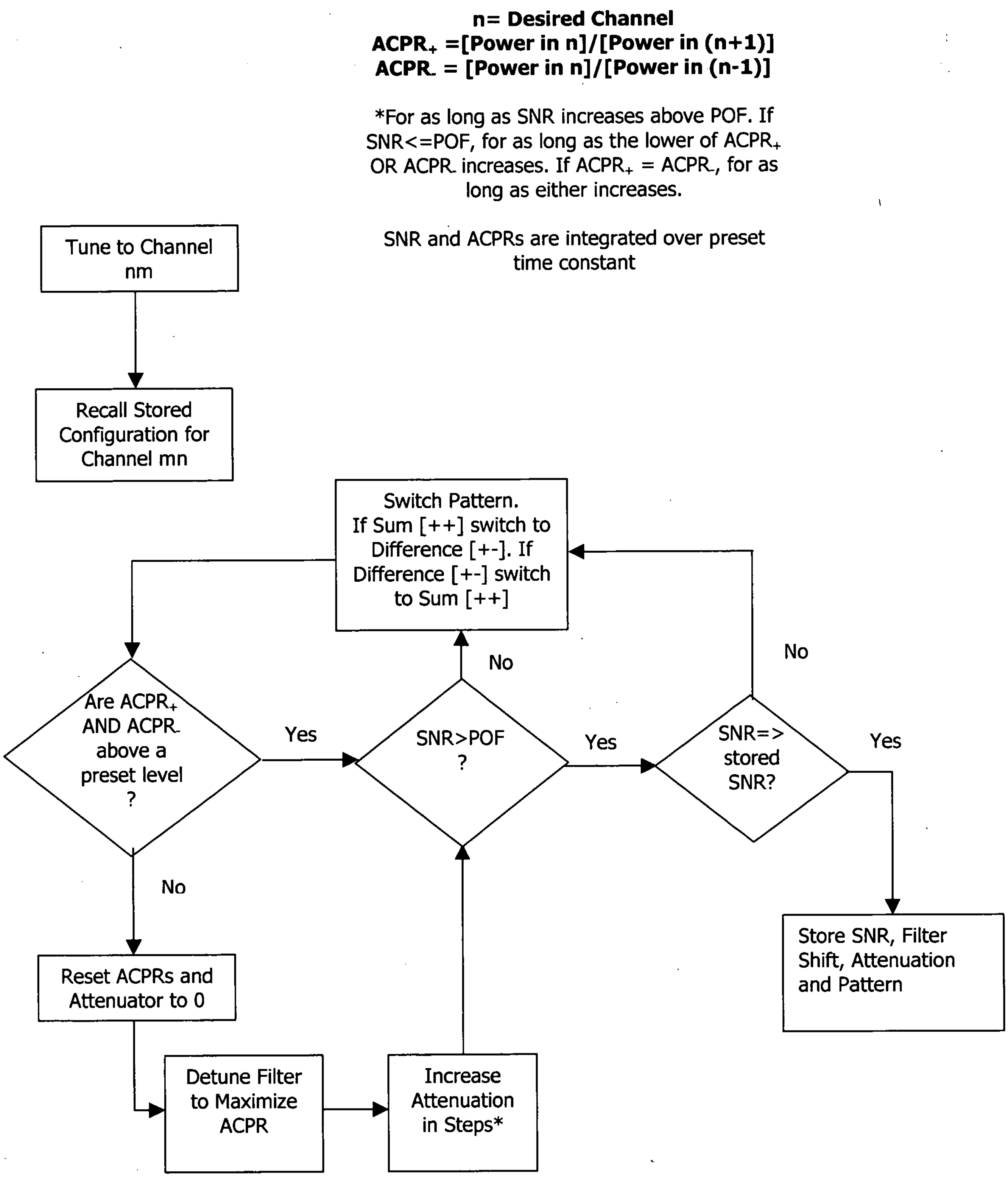


Figure 5: Optimization Algorithm for Mobile Reception